Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 72 (2015) 222 – 229

Energy Procedia

International Scientific Conference "Environmental and Climate Technologies – CONECT 2014"

Reducing household electricity consumption through demand side management: the role of home appliance scheduling and peak load reduction

Ilze Laicane*, Dagnija Blumberga, Andra Blumberga, Marika Rosa

Riga Technical University, Institute of Energy Systems and Environment, Azenes iela 12/1, Riga, LV 1048, Latvia

Abstract

One of the key issues arising from extended smart metering roll-out across Europe is how the data obtained from the meters may be used to provide end users with important information on energy-saving advice, which is one of the main principles of demand side management (DSM). The investigation of the potential for demand side management to reduce peak load were evaluated in this study. One four-person household was surveyed with the aim to find out user activities within the house, in particular, the use of appliances. Two appliances – a washing machine and dishwasher - were selected for assessing the potential for load shifting. The derived results show that, as a result of washing machine and dishwasher load shifting, the peak load of a dwelling can be reduced on average by 24 % and 13.5 %, respectively.

Peer-review under responsibility of Riga Technical University, Institute of Energy Systems and Environment

Keywords: Smart meters; household electricity consumption; user behavior; demand side management

1. Introduction

Climate and energy targets for 2020, called as "20-20-20", are focused primarily on improving energy efficiency at all stages of the energy system. Households represent 25 % of European energy consumption [1]. Promotion of energy efficiency in the household sector is therefore an important target for policy makers in the EU. Improvement of energy efficiency in households can be achieved through demand side management (DSM). In the context of a

* Corresponding author. Tel.: +37126299018; fax: +37167089908
E-mail address: ilze.laicane@rtu.lv

1876-6102
Peer-review under responsibility of Riga Technical University, Institute of Energy Systems and Environment
doi:10.1016/j.egypro.2015.06.032

smart grid system, Gelazanskas and Gamage gave the following definition: "Demand side management is the planning, implementation and monitoring of utility activities that are designed to influence customer use of electricity" [2]. Kostková et al. highlighted that load curtailments in times of peak demand or to shift loads to times of low demand are demand side measures which are most widely used [3]. As pointed out in Bergaentzlé et al. study, different DSM tools enable for consumption control to improve energy efficiency and achieve environmental targets [4]. They highlighted several DSM tools used to enhance system efficiency, such as: 1) information feedback and 2) dynamic pricing with or without direct load control (for example, time-of-use pricing, critical-peak pricing, peak-time rebate, real-time pricing and inclining block rate) [4]. Other studies emphasized load scheduling from on peak to off peak times as an effective tool for consumption reduction with the additional economic and environmental gains [5, 6] or to achieve financial savings for the customers [7, 8]. Panapakidis et al. indicates that the wider deployment of smart meters is an important tool that can enhance DSM implementation and reduce household consumption [9]. They emphasize the main advantage of the smart meters that allow for automatic collection of in depth information about the customer's behaviour thereby promoting new opportunities for energy saving and efficient management [9].

Vassileva et al. [10] pointed to demand response (DR) as a key element in the concept of the smart grid. The roll-out of smart meters in Europe has increased considerably in recent years. While the regulatory framework of smart metering is still taking shape, up to today 10 % of EU households have smart meters [11]. The recent prognosis shows that penetration of smart meters in households will increase rapidly in the next years due to binding targets set in DIRECTIVE 2009/72/EC: 80 % of the EU households should be provided with smart meters by 2020 [11−12]. A crucial argument in the debate around smart metering deployment in the EU is the potential for reduction and providing additional feedback to households on their energy consumption that will lead to energy savings [13]. Mohassel et al [14] pointed out that providing consumption data for consumer and load limiting for DR purposes are key features of smart meters.

Demand Side Management initiatives in the Latvian household sector have been studied previously [15−19]. For the purpose of our study, we analysed four person family households which participated in a smart metering project. In this study we focus on load shifting modelling to off-peak times for two selected appliances – washing machine and dishwasher.

2. Methodology

2.1. Household electricity demand model

Time of Use Surveys (TUS) may be used to find out the pattern of household electricity use. The survey makes it possible to assess how the activities performed in household (i.e., the activities of the occupants) affect residential electricity use [20−27]. For the various appliances (n) in the household, the aggregate electricity demand can be modelled over time [28]:

$$L_t = \sum_{i=1}^{n} a_{it} P_i \quad (1)$$

where
L_t – household's power demand, kW;
n – appliances in operation at time t;
P_i – the maximum power demand at time t, kW;
a_{it} – the power demand coefficient of the given appliance at a particular time.

2.2. Peak load reduction model

One of the key DR measures is to minimise the magnitude of peak loads. Blumsack and Fernandez [29] pointed out that smart meters allow for automatically controlled loads with the possibility of shifting peak loads. According to Gils [30] the theoretical DR potential in the residential sector through shedding is up to 37 GW. Shiftable loads are heating, cooling, air conditioning, washing machines, tumble dryers and dishwashers.

Dlamini and Cromieres [31] simulated the load reduction effectiveness by applying algorithms for load moving from high demand times (i.e. peak times) to low demand times (i.e. off peak times). The results showed that peak load can be reduced to at least 6 %. They concluded that washing machines, dishwashers, water heaters with storage, rice cookers, clothes dryer (tumble dryer) and vacuum cleaner were among appliances that can be flexibly moved to off-peak times [31]. The load shifting algorithm, introduced by Dlamini and Cromieres [31] can be expressed by the following equation:

$$L_{max} - L_{min} > min\, \Delta\, a_{it}\, P_i \quad (2)$$

where

L_{max}, – the highest L_t value among L_1 to L_r (see equation (2));

L_{min} – the lowest L_t value among L_1 to L_r;

$\Delta a_{it} P_i$ represents energy consumption changes.

As highlighted by Dlamini and Cromieres [31] load shifting is beneficial when L_{max}–L_{min} is the degree of the smallest possible adjustment of the given appliance a. The effectiveness of load shifting can be described by the load-levelling effect (LLE) of appliances use to smoothen the load. Accordingly, the aim of the shifting algorithm is to test the LLE of flexible loads from peak times to selected shifting period of off-peak times. LLE can be estimated from the following relationship:

$$LLE = \frac{(L_{max2}/\, L_{min2})}{(L_{max1}/L_{min1})} \quad (3)$$

where L_{max} and L_{min} represent the maximum and minimum load values before and after the load levelling designated by the subscripts 1 and 2, respectively.

The peak load ratio (PLR) can be expressed through the load levelling effect as a measure of use efficiency as follows:

$$PLR = \frac{L_{max2}}{L_{max1}} \quad (4)$$

Peak load limit L_{lim}, less than L_{max1} can be requirement at all times:

$$\sum_{i=0}^{n} a_{it}\, P_i \leq L_{lim} \quad (5)$$

The peak times at 05:00 to 08:00 and 17:00 to 21:00 were selected for testing the load shifting algorithms, but the off peak times were selected among 10:00 to 16:00 and 23:00 to 04:00 [31].

In another study Caprino et al. [32] used a technique for the electric load management based on real-time scheduling for peak levelling. Common household appliances are modeled in terms of timing parameters. The considered loads are classified as time-triggered (refrigerators, heating, ventilating and air conditioning systems) or event-triggered by the user (electrical oven, dishwasher, washing machine, etc.). The results showed that peak load can be reduced up to 46 % preserving the quality of service of each load at the same time. The scheduling of periodic loads based on small-scale systems has been proposed in [33] where peak demand can be reduced by about 40 % or more. Powells et al. [34] highlighted that laundry and dishwashing loads are quite flexible for shifting, but cooking and other kitchen appliances – Inelastic. Nevertheless reduction of household peak power demand is largely dependent on human behaviour [35].

3. Results

Based on the recently launched smart metering project "Promotion of energy efficiency in households using smart technologies", it is possible to monitor household consumption in real time with 5 minute interval recording. In total, 500 Latvian households have been equipped with smart meters at the beginning of 2013. For the purpose of our study we analysed one particular 4-person household (2 adults, 2 children) enrolled in the pilot project. Highly detailed hourly consumption data from the smart meter during the first year of the project (in a 12-month period from April 1st, 2013 till March 31st, 2014) have been obtained and used for the analysis.

In order to assess the flexible loads for shifting, first, an in-depth household survey was carried out. Household's characteristics (personal, socio-economic data of family members), number of appliances, time of use and daily usage habits have been found out during the survey household survey. In particular, the number, type, power of home appliances, usage frequency, the exact use of the time during the day, as well as specific usage habits and modes were among the main issues clarified during the questionnaire. The residents' activities and occupancy profiles were differentiated between weekdays and weekends, as well as summer and winter time. Distinguishing between weekdays and weekends, as well as summer and winter time, was chosen in order to evaluate what similar and different aspects can be observed based on the type of day, or season of the year and how associated people's activities and behaviour can affect the pattern of electricity use. Since the task of our research was to assess possible load shifting from the peak times to off-peak times, during the interview it was found that two households appliances – washing machine and dishwasher – are suitable for load shifting. This household uses the washing machine twice a week (2 times on Thursdays) between 9:00 till 18:00. The dishwasher is used almost every day – every weekday at 12:00‒14:00 and once every other work day between 24:00‒2:00. For the purpose of our study, we used a similar approach for efficient load shifting to minimize peak loads as described in [28-29; 32‒34]. For this purpose we will compare the household's daily load curve with typical Latvian daily curve. In case of load shifting for the washing machine we compared Latvian daily curve with the household's average load curve on Thursdays in a selected winter month January and selected summer month July. Similarly, the average load curve on weekends in January and July was chosen for dishwasher load shifting. Figure 1 presents a comparison of load for investigated household with typical Latvian consumption.

As it can be seen from Figure 1, the studied household's electricity consumption curve is only partially comparable with the typical Latvian consumption curve. The typical "peak consumption" in Latvia falls within the time periods from 6:00 to 8:00 and from 17:30 to 21:30 [35]. Higher "peaks" are on evening hours in winter [30]. In the liberalised electricity market, electricity in Latvia is traded on the basis of hourly consumption. The typical load distribution curve is calculated based on the percentage distribution of the total daily energy consumption that is calculated taking into account system load data. All consumption curves show higher "peaks" on evening hours in winter. The weekend morning "peaks" can be observed in later hours of the morning (starting from 9:00) than on weekdays (starting from 7:00). Looking to the smart metering data obtained from the studied household for January and July (see dotted curves in Fig. 1 a) and Fig 1 b)), differences can be observed regarding washing machine usage on Thursdays. Looking at the data, it is most likely, that in January the washing machine is used from 15:00-18:00. It is quite difficult to predict usage in July however, because several "peaks" occur in the time period between 9:00 – 17:00.

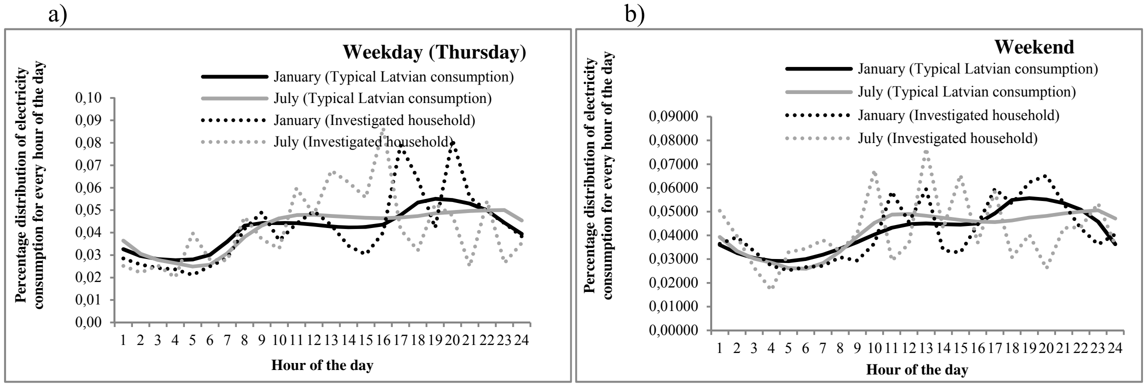

Fig. 1. Studied household consumption curve compared with typical daily curve in Latvia: a) working days; b) weekends.

As mentioned previously this household uses their washing machine twice a week (2 times on Thursdays). The capacity of the washing machine is 2.2 kW, and an average electricity consumption of washing machine per cycle can be estimated at 1.24 kWh. Hence, we calculated that the average consumption for shifting is 2.48 kWh. We propose to shift the washing machine load to 14:00–16:00 in the winter and to17:00–19:00 in the summer. The dishwasher is used almost every day – every weekday at 12:00–14:00 and once every two work days from 24:00–2:00. As revealed in the interview, the household has already been using the opportunity to delay start for the dishwasher to 24:00–2:00 on work days. Consequently, the dishwasher load shifting to another time on work days was not evaluated within this study. The capacity of the dishwasher is 2.2 kW and the average electricity consumption of the dishwasher per cycle can be estimated 1.06 kWh/cycle. The average dishwasher consumption of 1.06 kWh is proposed for shifting to 14:00–16:00 in the winter and to 19:00–21:00 in the summer. The results of load shifting are presented in Figure 2.

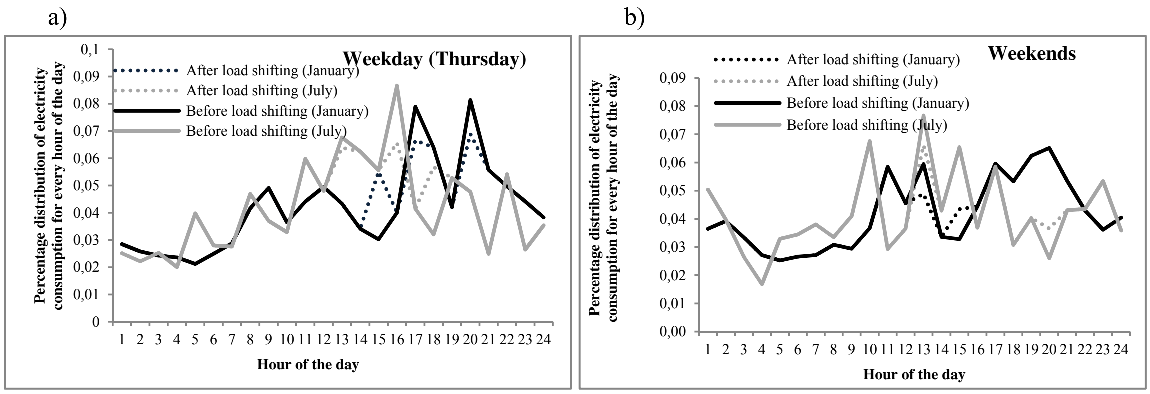

Fig. 2. Load profiles before and after peak load reduction on: a) working day (Thursday); b) weekends (Saturday, Sunday).

It can be seen that household load curves are evened out due to estimated peak load reduction of the washing machine and dishwasher. In case of dishwasher load shifting in the winter on weekends it was not possible to reduce evening peak consumption (at 19:00–20:00), because the dishwasher is used in the afternoon. It was possible to shift the load to the later afternoon time, but this does not reduce evening peak.

In order to assess load shifting efficiency, we implemented the algorithm for **load transfer to off-peak hours found in** Dlamini and Cromieres [31]. The purpose of the shifting algorithm and equations are described in section 2.2. Table 1 shows a summary of load shifting algorithm implementation on the household aggregate load.

Table 1. Effect of algorithm implementation on aggregate load [31].

Appliance	Before load shifting (levelling)		After load shifting (levelling)		Load-levelling effect (LLE)	Peak load ratio (PLR)
	L_{max}	L_{min}	L_{max}	L_{min}		
Washing machine (winter)	0.08133	0.03028	0.06893	0.02120	1.210535	0.847535
Washing machine (summer)	0.08663	0.03203	0.06563	0.02003	1.211463	0.75759
Dishwasher (summer)	0.07666	0.01683	0.06759	0.01683	0.881685	0.881685

As dishwasher load shifting in winter did not result in reduced maximum load (i.e., evening peak load) the LLE and PLR for this particular case were not calculated. As it can be concluded, washing machine load shifting in the summer shows the higher peak consumption reduction with PLR = 0.76. It indicates that peak load can be reduced by 24 %. In case of washing machine load shifting in the winter, it is possible to reduce losses by 15 %, but in case of dishwasher load shifting (summer) a reduction of 12 % can be observed.

4. Conclusions and discussion

The purpose of the study was to analyse electricity consumption for one four person family household. This household is participating in a recent smart metering project in Latvia. The household survey was carried out with the aim to obtain information about household characteristics (personal, socio-economic data of family members), number of appliances, time of use and daily usage habits. The load shifting algorithm based on the recent study was applied to two appliances in the household: washing machine and dishwasher. In the study it was found that significant peak load reduction of at least 24 % and 13.5 % can be reached due to washing machine and dishwasher load shifting, respectively. Appliance load shifting is a reasonable way for reducing peak consumption. Our results show higher peak load reduction as in Dlamini and Cromieres study [31] (reduced by at least 6 %), but lower results as in Caprino et al. study [32] (up to 46 % reduction) and Nghiem et al. study [33] (reduction by about 40 % or more).

However, the results imply that load shifting can be achieved only by changing user behaviour. Therefore, the main challenge is to develop appropriate demand management and customer education programs that are targeted towards reducing or changing patterns of electricity use in the household. The main question would be how to get people's attention to start using appliances at off peak times when the electrical network is less loaded. Many factors, such as, interruptible loads, time of use elasticity and user willingness to refuse impulsive use of appliances, contribute to the peak load reduction. By increasing customer awareness and participation in demand management, it is possible to spur demand side flexibility much more effectively.

Acknowledgements

The work has been supported by the National Research Program "Energy efficient and low-carbon solutions for a secure, sustainable and climate variability reducing energy supply (LATENERGI)".

References

[1] EEA, 2013. Achieving energy efficiency through behaviour change: what does it take? European Environment Agency (EEA. Available at http://www.eea.europa.eu/publications/achieving-energy-efficiency-through-behaviour [accessed 1.09.14].

[2] Gelazanskas L, A.A. Gamage K. Demand side management in smart grid: A review and proposals for future direction. *Sustainable Cities and Society* 2014;11:22–30.

[3] Kostková K, Omelina L, Kycina P, Jamrich P. An introduction to load management. *Electric Power Systems Research* 2013;95:184–191.

[4] Bergaentzlé C, Clastres C, Khalfallah H. Demand-side management and European environmental and energy goals: An optimal complementary approach. *Energy Policy* 2014;67:858–869.

[5] Rious V, Roques F, Perez Y, Which electricity market design to encourage the development of demand response? Robert Schuman Centre for Advanced Studies, EUI RSCAS Working Paper, 2012/12.

[6] Albadi M.H, El-Saadany E.F. A summary of demand response in electricity markets. *Electric Power Systems Research* 2013;78(11):1989–1996.

[7] Middelberg A, Zhang J, Xia X. An optimal control model for load shifting – with application in the energy management of a colliery. *Applied Energy* 2009;86(7-8):1266–1273.

[8] Van Staden A.J, Zhang J, Xia X. A model predictive control strategy for load shifting in a water pumping scheme with maximum demand charges. Applied Energy 2011;88(12):4785–4794.

[9] P. Panapakidis I, A. Papadopoulos T, C. Christoforidis G, K. Papagiannis G. Pattern recognition algorithms for electricity load curve analysis of buildings. *Energy and Buildings* 2014;73:137–145.

[10] [Vassileva I, Wallin F, Dahlquist E. Understanding energy consumption behavior for future demand response strategy development. *Energy* 2012;46:94–100.

[11] Joint Research Center. Energy: Commission paves the way for massive roll-out of smart metering systems, Brussels, 9 March, 2012.

[12] DIRECTIVE 2009/72/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 July 2009 concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC, Official Journal of the European Union, 55/112L, 14.8.2009.

[13] Joachain H, Klopfert F. Smarter than metering? Coupling smart meters and complementary currencies to reinforce the motivation of households for energy savings. *Ecological Economics* 2014;105:89–96.

[14] Mohassel RR, Fung A, Mohammadi F, Raahemifar K. A survey on Advanced Metering Infrastructure. *International Journal of Electrical Power & Energy Systems* 2014;63:473–484.

[15] BoloninA. Rochas C, Kibure I. Rosa M, Blumberga D. Compact Solar Combisystem for an Apartment Building. *Environmental and Climate Technologies* 2010;4(1):29–34.

[16] Kamenders A, Blumberga A. Multi-Objective Optimization Approach for Improving Performance of Building, *Environmental and Climate Technologies* 2009;3(3):70–73.

[17] Laicāne I, Blumberga A, Rošā M, Blumberga D, Bariss U. Forecasting electricity consumption based on smart metering case study in Latvia. Proceedings of the 8th WSEAS International Conference on Energy & Environment „Recent Advances in Energy and Environmental management" 2013;13:148-156.

[18] Laicane I, Blumberga A, Rošā M, Blumberga D. Assessment of Changes in Households' Electricity Consumption, *Agronomy Research* 2013;11(2):335–346.

[19] Bariss U, Laicane I, Blumberga D. Analysis of Factors Influencing Energy Efficiency in a Smart Metering Pilot. *Energetika* 2014;60(2):125–135.

[20] Widen J, Lundh W, Vassileva I, Dahlquist E, Ellegard K., Wäckelgard E. Construction load profiles for household electricity and hot water from time-use data. Modelling approach and validation. *Energy and Buildings* 2009;41:753–768.

[21] Richardson I, Thomson M, Infield D. A high-resolution domestic building occupancy model for energy demand simulations, *Energy and Buildings* 2008;40(8):1560–1566.

[22] Widén J, Wäckelgård E. A high-resolution stochastic model of domestic activity patterns and electricity demand. *Applied Energy* 2010;87:1880–1892.

[23] Richardson I, Thomson M, Infield D, Clifford C. Domestic electricity use: a high-resolution energy demand model. *Energy and Buildings* 2010;42(10):1878–1887.

[24] Chiou YS, Carley KM, Davidson CI, Johnson MP. A high spatial resolution residential energy model based on American Time Use Survey data and the bootstrap sampling method. *Energy and Buildings* 2011;43:3528–3538.

[25] López-Rodríguez MA, Santiago I, Trillo-Montero D, Torriti J, Moreno-Munoz A. Analysis and modeling of active occupancy of the residential sector in Spain: an findicator of residential electricity consumption. *Energy Policy* 2013;62:742–751.

[26] Santiago I, López-Rodríguez MA, Gil-de-Castro A, Moreno-Munoz A, Luna-Rodríguez JJ. Energy consumption of audiovisual devices in the residential sector: economic impact of harmonic losses. *Energy* 2012;60:292–301.

[27] López-Rodríguez MA, Santiago I, Bellido-Outeiri˜no FJ, Moreno-Munoz A, Trillo-Montero D. Active occupancy profiles in the residential sector in Spain as an indicator of energy consumption, in: IEEE Second International Conference on Consumer Electronics, ICCE, Berlin, 2012:1–5.

[28] G. Dlamini N, Cromieres F. Implementing peak load reduction algorithms for household electrical appliances. *Energy Policy* 2012;44:280–290.

[29] Blumsack S, Fernandez A. Ready or not, here comes the smart grid! *Energy* 2012;37:61–68.
[30] Gils HC. Assessment of the theoretical demand response potential in Europe. *Energy* 2014;67:1–18.
[31] G. Dlamini N, Cromieres F. Implementing peak load reduction algorithms for household electrical appliances. *Energy Policy* 2012;44:280–290.
[32] Caprino D, Marco L, Vedova D, Facchinetti T. Peak shaving through real-time scheduling of household appliances. *Energy and Buildings* 2014;75:133–148.
[33] Nghiem TX, Behl M, Mangharam R, Pappas GJ. Green scheduling of control systems for peak demand reduction. IEEE Conference on Decision and Control and European Control Conference 2-11; 5131–5136.
[34] Powells G, Bulkeley H, Bell S, Judson E. Peak electricity demand and the flexibility of everyday life. *Geoforum* 2014;55:43–52.
[35]The *average hourly load* curve in Latvia. Available at http://www.sadalestikls.lv/lat/partneriem/informacija_tirgotajiem/ikstundas_paterina_sadalijuma_grafiks/1971-ikstundas-paterina-sadalijuma-grafiki/ [accessed 1.09.14].